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Preliminary Draft

IMPLICATIONS OF ON-LINE, REAL-TIME SYSTEMS FOR MANAGERIAL DECISION MAKING*

by

Donald C. Carroll

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Associate Professor of Management
Alfred P. Sloan School of Management and
Staff Member, Project MAC
Massachusetts Institute of Technology
Cambridge, Massachusetts

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I. Introduction

Statement of Purpose

A management organization exists for the fundamental purpose of making decisions and is therefore structurally dependent on the nature of the decisions and its decision-making entities; decision-making is manifestly an information dependent process and can therefore be profoundly affected by new information technology. It is my purpose to proceed backwards through this chain of dependency as follows: first, to review a rapidly expanding development of information technology, namely, on-line, real-time systems; second, to identify some effects of this technology on managerial decisions; and, finally to note some proximate implications on decision systems, which is to say, organizations.

On-Line, Real-Time Systems

The designation "on-line, real-time" is commonly used to encompass such diverse applications as closed-loop, continuous process control as employed in oil refineries and chemical plants, air defense coordination as in SAGE, airline reservations and flight seat inventory control as in SABRE, and multiple user, on-line computation as provided by the so-called "time-sharing" systems. All of these are characterized by a system capability for rapid response to stimuli at numerous and distant terminals. The temptation therefore exists to contrast these systems with conventional "batch-processing" computer systems which have no such capability. However, what I will be discussing might be called "compatible" on-line, real-time systems, using Corbato's [6] nomenclature. For what is envisioned is a configuration

which permits not only real-time response, but which also can provide conventional processing capabilities (subject to interruption and restoration). These computer systems represent a spatial and temporal extension and generalization of previous capabilities, and as such, are the most flexible (and most expensive) mutation evolved by the computer industry.

Actually, the hardware technology is not new; most of it was available a decade ago. But only recently have we achieved sufficient economy in manufacture and sophistication to exploit the powers inherent in the hardware. In Part II of this paper, the characteristics, capabilities, and current state of development of these systems are discussed.

Computers and Decision-Making

In general, computers can have two different effects on decisions. One effect is upon the quality of information inputs, or to use the current vernacular, the "data base," the body of relevant data that can be marshalled for the decision-making mechanism. There are two dimensions of quality of interest here: the currency ("age") of the data and its scope ("globalness").[1] They depend more upon the communications network and provisions for file accessibility than upon the power of the central processor. Such phrases as "better information faster" refer to data base quality. The second effect relates to the methodological or procedural aspects of decision-making. Some information processing portions of decisions can be performed by the computer; a division of labor between man and machine is one type of effect. The other is a question of entirely new procedures made possible by the computational

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[1] A third dimension, accuracy, is also affected, but it is not of compelling relevance here.

or pseudocognitive powers of the computer. These effects depend to a degree on the size and power of the central processor but depend crucially on the programs which employ that power. The phrases which apply to this aspect are "amplifiers of intellect," or "machine-aided cognition," among others.

One of my propositions is that on-line, real-time computer systems provide the ultimate capabilities in both the data base and procedural aspects of decision-making. This is argued in Part III, using both Anthony's [1] and Simon's [32], classifications of decisions. It should be noted that portions of this proposition have been argued before: with considerable foresight by Malcolm [24], and with evangelical zeal by Sprague [33].

Organizational Effects

That decision-making will change appears to be an inescapable conclusion; that organizations will change as a consequence, equally so. But, except for some new aspects of the centralization-decentralization issue, the particular changes foreseen here are not significantly different from those predicted by Simon [32] and Leavitt and Whisler [20]. What is argued, however, is that the added dimension of flexibility in the generalized computer systems supplies the missing link between the potential of information technology in management, as perceived by them, and the rather modest (in light of the funds invested) state of current accomplishment in this field.

Part IV is dedicated to a discussion of these implications, a thumbnail review of the current state of accomplishment, and a summary.

II. The Nature and Capabilities of On-Line, Real-Time Computer Systems[2]

Working Definition

The following is advanced as a working definition of an on-line, real-time system. Remotely located transaction origination stations are connected directly ("on-line") to the central processor and transactions are processed immediately upon origination (in "real-time"), subject only to delays resulting from the processing of the transaction itself and from queuing behind transactions of earlier origination or otherwise higher priority. To fulfill the requirement of "real-time," these delays must be negligible in the context of the particular application.[3] Often, there is maintained a backlog of lower priority "background" programs which occupy the central processor when it is otherwise idle, that is, until a real-time transaction requires processing and interrupts the background operation. It is this background compatibility that makes on-line, real-time systems an extension of rather than a substitution for conventional "batch" oriented processing.

On-Line, Real-Time "Management" Systems

One popular application of these systems is in providing remote inquiry of a central status file. Real-time inquiry is the simplest form of manage-

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[2]Some definitions are drawn from [3] and [4].

[3]The delay specifications for real-time systems vary widely among applications. For closed-loop continuous process control, maximum delays of a few milliseconds may be intolerable; for casual file status inquiries, mean delays of a minute or two may be quite acceptable.

ment employment. Frequently, but not always, the file is updated in real time as well. A more advanced application is operations, or more generally, process control. If the transactions report changes in the state of the environment, and if the central processor responds with control directions, then the system is an on-line, real-time control system.[4] The purpose is to obtain control directions before the states have changed materially, so the effect is response to events "while they are happening." Between the extremes of real-time inquiry of periodically updated files and automatic process control, there exists a number of intermediate possibilities, notably "non-automatic" control in which the processor responds with "suggestions" instead of directions.

A component normally on-line in these systems is some type of mass storage device which enables access to any particular record in the file in order to provide an appropriate response. The idea is that the detailed environment status accounts are updated continuously as transactions occur. And in most cases there are provided routines for making the numerous detailed control decisions as status changes occur "on the firing line."

Basic Capabilities

There are two capabilities, of basic importance, which are unique to

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[4] I am precluding from this discussion the class of specialized real-time systems, typically employed in continuous process control. These computers are "dedicated" to the one function primarily because it requires continuous "round-robin" polling of status measuring instruments. Attention here will be focused on general purpose real-time systems.

these on-line, real-time systems. They are:[5]

1. The capability of maintaining a (practically) current, global data base. A global data base is one containing status records on all relevant environmental entities, regardless of how physically remote they may be.

2. The capability of bringing substantial computational power to bear on decision problems in real-time, i.e., at the moment of decision, again regardless of how distant the subject of the decision might be.

The first clearly has relevance to the "data base quality" aspect of decision-making, currency and globalness representing ultimates in quality. The second reflects a potential in the procedural employment of the computer, i.e., programmed decision-making.

State of the Art

A rather large number of such systems have been developed and are in use now. The earliest, and in many respects, the most important prototype was SAGE [24,33]; the American Arilines SABRE reservation system [8,29] is the largest commercial operation; Westinghouse and Lockheed [2] employ them for distribution and manufacturing control, respectively; and numerous banks and insurance companies have or are developing systems [33]. It is noteworthy

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[5]There are, of course, other desirable aspects. To mention a couple, because the processing of a transaction takes place while the originator is on-line, unique opportunities for input error detection, correction or clarification exist, and direct input-output avoids many problems associated with media conversions (e.g., hard copy to cards, cards-to-tape, tape-to-printer) associated with conventional processing.

that, excepting SAGE, most of these systems have exploited only the data base aspect; they have not tapped the procedural power to any major extent.

Time-Sharing Systems

A more recent employment of the on-line, real-time configuration has been in "time-sharing" the central processor (and its files) to provide multiple users with simultaneous access. The idea is that the services of the computer are rapidly commutated among the several users, who are stationed at remote teletypewriter-like consoles, providing each active user with a short burst ("quantum") of exclusive service.[6] With limited high-speed memory, this involves "swapping" some portions of the user programs in and out.

The purpose of these systems is to alleviate the necessity of delay between problem solver's proposal and computer's disposal or the expensive alternative of the computer's awaiting human reactions to its responses. Since the probability is high that some subset of the users will require computational service during a given round of the "commutator," the fact that the complementary subset of users may be lost in thought does not result in idle capacity.[7] Background programs may also be employed as a further guarantee of high utilization.

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[6] For more comprehensive discussion see [16]. The original concept is credited to Corbato and McCarthy [25] and Corbato [6] has led the design and development.

[7] At Project MAC, M.I.T. there is current provision for thirty active users. There are over two hundred terminals at M.I.T. and several others located across the country. For a discussion see Fano [12].

Basic Capability

The end product of time-sharing is the provision of an interactive or "conversational" relationship between the human (or humans) and the computer. In effect, this enables close cooperation between man and machine in problem solving without incurring exorbitant cost.

Conventional computer systems have required large backlogs of work (and concommitant long processing delays) in order to guarantee high utilization and, as a result, have decoupled the user from the running of his programs. Licklider [21, p. 20] notes that this has resulted in the "heuristic" aspects of problem solving, that is, "the setting of goals, the generation of hypotheses, the selection of criteria ..." being almost wholly separated from the "algorithmic" aspects, the computer's computational treatment of the problem presented to it. He goes on to conclude [p. 20]:

> Conventional digital computing is limited in application to those problem areas in which such separation can be made ... essentially the domains in which the problems have already been solved ... The vast majority of the problems of the frontier--of the unsolved problems that scientists, engineers, managers, administrators and commanders are going to solve in the coming years--are characterized by an intertwining of heuristic and algorithmic threads.

And the intertwining requires time-sharing.

Since time-sharing permits a flexible division of labor between man and machine, as well as a temporal comingling of the two, it has profound implications for the procedural aspects of decision making.

State of the Art

Time-sharing is a rapidly maturing technology. Since the first large-scale installations at System Development Corporation and M.I.T. in 1963,

on the order of twenty other major installations have been undertaken. On the older systems, a great deal of experience has been gained, which experience appears to confirm the speculation of time-sharing advocates as to man-machine "symbiosis" [3,12,20].

The early systems were constructed from conventional computers and required substantial compromises and jury-rigging. Now, large computer systems are being designed specifically for time-sharing applications [7,30].

Mutual Compatibility and Capability

It is important to note that on-line, real-time control systems and time-sharing are based on the same technology,[8] and hence are mutually compatible as well as individually compatible with "background," i.e., conventional data processing. That is to say, a human problem solver interacting with a computer can be treated as another transaction origination station, being allowed to interrupt programs of lower priority and, in turn, being interrupted by real-time transactions as they arise.

We can therefore postulate the existence of totally flexible and general computer systems which provide simultaneously three crucial capabilities: a current, global data base; substantial computational power available for real-time decision making; and a convenient, efficient man-machine inter-

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[8]Both require program priority assessment, management of the memory images of several active programs, including "protection" of programs from each other, and complicated "interrupt" features. The various problems exist in different degrees in different applications, of course.

face providing for data access and cooperative problem solving. And this implies that in a given problem context, whatever permutation or combination of human and machine problem solving attributes is needed can be supplied with data inputs of whatever quality of currency or scope is desired.

State of the Art

As such, a totally generalized system has not been constructed except in military systems, e.g., SAGE, NORAD. However, in additional support of the argument of their general feasibility, it may be germane to note that my group at M.I.T. has simulated such a system on the time-sharing system at Project MAC [4].

III. Effects on Managerial Decision Making

Introduction

Decisions obviously differ as to their scope and purpose and the nature of their inputs. For purposes of gross classification then, it is convenient to draw on Anthony's [1] division of all management functions into three parts, namely, operational control, management control, and strategic planning. On the other hand, decisions differ also by virtue of their specificity of procedure or structure. Accordingly, I will employ Simon's [32] polarization of decisions as programmed and non-programmed within the functional categories.

Effects on Operational Control

Anthony [1,p. 18] defines operational control as follows: it is "the process of assuring that specific tasks are carried out effectively and efficiently." It includes such activities as planning "aggregate production, inventories, and work force"[9] as well as the detailed day-to-day decisions controlling the execution of basic production tasks. As such, it may occupy several levels of management (including the top from time-to-time).

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[9] Such as that discussed in [19]. I may be taking some liberties with Professor Anthony's scheme, but the criterion of inclusion here is that the decision constitutes a direct input to the operating system.

Programmed Operational Control

First, consider the detailed operating decision level which often consists of thoroughly "programmable" decisions that appear to invite automation. It is my contention that on-line, real-time systems provide the wherewithal for this automation and that without the capabilities of current, global data base and computer power for real-time decisions, this automation is not generally possible. Thus, the systems are a prerequisite for realization of Simon's [32,p. 49] "... layer of programmed (and probably largely automated) decision processes for governing the routine day-to-day operation of the physical system..." Furthermore, there exist strong economic pressures for this automation, it is contended.

To pursue this, consider some alternative structures for detailed operating control decisions.[10] One extreme might be called local real-time; the decision is made locally (i.e., not centrally) and, while the decision maker has current information, its scope is limited to the locale and no computational assistance is available to him. An example of a local real-time operational control system is found in the use of a "dispatcher" in a factory. The dispatcher's job is to reconcile all of his local information (and perhaps some crude global inputs such as scheduled start dates for the jobs, which may reflect some expectations as to the situation elsewhere in the factory).

At the next higher level of sophistication is the global periodic structure in which full environmental status and (perhaps) sophisticated

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[10] The material in this section is discussed at length in [4].

computer programs are used to provide a detailed schedule for each task to be performed. This schedule is computed some considerable time before real-time execution of the tasks. At execution time, the schedule can be consulted and, in theory, supplies the executor with a direct statement of what to do next. Examples of this type of structure range from the periodically reshuffled Gantt chart to complex capacity allocating PERT schedules or linear programmed shop schedules; all of these attempt to lay out a program of activities for some future period.

There are clearly an infinite number of intermediate structures between local real-time and global periodic. As more resources and sophistication are injected into the schedule determination, more weight is placed upon its indication in the real-time dispatching process.

Some Problems with Conventional Structures

Both of these alternatives have major flaws. In a local real-time system, because the decision maker is innocent of full environmental status, he is apt to make decisions which appear optimal to him but which are not, all effects considered, in the overall corporate interest. For example, a job shop dispatcher may select for performance one high priority job ahead of another not knowing that the next work station on the favored job's routing is broken down.[11] Or he may fail to select a job whose delay is

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[11] I use the job shop for examples because my experience and research have been concentrated on this problem area. However, there are analogies to job shop problems in almost all resource-constrained operations. My students have found elements in hospitals, research and development laboratories, ice cream plants, and even within computers themselves. Hence, I hope that these examples will not be narrowly construed.

holding up several other components awaiting assembly elsewhere in the shop. What information the dispatcher has is current, in most cases, but its scope is inadequate and this flaw leads him to make "locally suboptimal" decisions.

Global periodic systems may operate with less than perfect effectiveness due to a different data base defect. Because the schedules are issued well ahead of execution, they are subject to prediction errors of two types. First, errors in processing time estimates can result in the infeasibility of the schedule. If a task takes longer than estimated, for example, the job will not arrive at the scheduled time at some subsequent work station and the task to be executed at that station cannot be executed when specified. Second, there are numerous events which cannot be predicted as to their exact time of occurrence, only at best as to their average incidence. Among these are machine breakdowns, unacceptable quality performance, worker absenteeism, strikes, lockouts, and acts of God. When they occur, the best laid schedule is no longer valid. Departures from validity naturally increase as time passes after calculation of the schedule, so there is a time-related <u>decay</u> process. When departures have to be made because of decay, they are typically made on the basis of local considerations. The data base defect leading to decay is lack of <u>currency</u>, i.e., failure to update the scheduling model when departures from predictions occur.[12]

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[12] Even when decay does not pose a serious problem, the collection of status data to drive the scheduling programs and the promulgation of the schedule to affected parties do. This has led some manufacturing firms to install on-line, real-time systems in conjunction with global periodic control, see [2, p. 38 et seq.]

Certainly neither local real-time, being inherently "manual," nor (with rare exceptions) global periodic systems provide "closed-loop," which is to say, automated operations control. And the flaws in both structures indicate the potential value in so doing.

On-Line, Real-Time Systems--Flawless (in Theory)

Neither local suboptimality nor decay need be problems within an on-line, real-time system since current global information can be made available for decisions on the firing line, so to speak. And, the computer's "algorithmic" power being available at the moment of real-time decisions, quite elaborate programs can be employed. Especially in manufacturing control, which abounds with chess-line combinatorial decision problems, the opportunity for employing powerful heuristic programs would appear particularly attractive.[13]

Naturally, the comparative advantage of on-line, real-time systems for operational control depends on several factors such as the degree of interdependency among operating entities, their physical dispersion, and the degree of unpredictability of the process being controlled. It is my assessment that most manufacturing firms have sufficiently complex, interdependent, and unpredictable operations that the advantage should be evaluated.

Non-Programmed Operations Control

At higher levels in the hierarchy of operating decisions (and in many cases at the lowest), there exist non-programmed decisions which decidedly

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[13] Research into this possibility is reported in [4].

(if possibly temporarily) do not have formal solution procedures. To note a few: at the lowest level there is the question of what to do when one of the afore-mentioned stochastic events occur; at the "structuring" level the questions might be whether to work overtime at some work station, or to shift some workers from one station to another, or to subcontract some tasks to another firm, or should we bid on this new order, if so, what due date can we quote without inviting disaster, and so forth.

It is for questions of this ilk that the possibility of man-machine cooperation becomes attractive. To elaborate on this, let me postulate the existence of a "largely automatic" on-line, real-time control system for a factory. Consider what facilities the system provides. First, at any moment in time, the true status of all jobs and all work stations is maintained in immediately accessible form in the data base. Second, a set of decision making programs exists, which programs control the behavior of detailed operations. These programs will also simulate <u>with perfect validity</u> their own response to any given set of inputs. This being the case, a man addressing himself to a problem of the type described has available (essentially without cost or effort) two superlatively useful items: a valid simulation model of the environment and a valid starting point (i.e., current environmental status) for its operation.[14] With a time-sharing facility he can ask, without hampering on-going control processes, a variety of "what would happen if?" questions and receive quick answers. That is, he can propose alternative solutions to his problems, and the ready-made simulation model will provide rapid evaluation of each.

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[14]Collecting starting point data is no trivial problem, see fn. 12 above.

Moreover, since the process is interactive, he can monitor the simulation in process for purposes of terminating unpromising alternatives or pursuing in depth those of more interest.[15]

There are a number of roles that could be fulfilled by a man in coalition with the machine. One is providing assistance to the automatic system. It is easy to program recognition of "difficult" decisions and to instruct the machine to call for help when it recognizes one. Another role is adaptation. There are always events so rare that it is simply uneconomical to program responses even if the appropriate response is known. The man can provide a useful source of general problem-solving capability to augment and extend the capability of the system. A third role is adjustment. The man sets the parameters--turns the knobs, so to speak--that govern the conditions faced by and behavior of the control system. These are the "structuring" activities referred to above. Each is materially to be aided by facilities for simulation and factual information retrieval from the data base.

The facility for multiple user cooperation on a single problem may also be usefully exploited. For example, consider how such an approach might be used in a capital goods manufacture [3,p. 8]. Current practice would likely call for rather sharp boundaries drawn between the functions of engineering, production management and marketing. Yet clearly these functions are interdependent. For instance, the engineers often specify the routing of particular orders through the factory, that is, the machine assignments and sequence of operations. The production manager, taking this routing as input, must decide

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[15]Such a man-machine system for a hypothetical job shop is the subject of current research, see [4].

on allocation of work station capacity to competing jobs, based on the situation as it arises and, not infrequently, considerable advice on priorities from marketing.

It would be perfectly feasible to establish plans for all three functions via their interaction with a common predictive model. Routing assignments could then reflect not only engineering considerations, but production congestion problems and marketing priorities as well. Additionally, marketing's efforts to acquire new business could be reconciled with engineering and production capabilities. Such team planning, if performed rationally, holds, as a consequence, great potential for elimination of additional suboptimal activity.

In the operations control function, the virtues of the generalized computer systems derives not only from the close coupling of man and machine but also in coupling the combination with the current, global data base and the automatic level.

Economic Virtues and Main Effects

In summary of this section, the desirable properties of this system's structure are, among others: improved hierarchical communication, i.e., higher level managers have their operating plans reconciled with detailed operations via simulation, this might be denoted as "vertical integration"; reduction of local and functional suboptimality, this might be called "horizontal integration"; provision of a completely flexible division of decision making labor between "heuristic" man and "algorithmic" machine, implying that a management system of considerable sophistication need not be completely specified before installation--major portions of the problem can be allocated, at least initially, to adaptive, ingeneous man.

Effects on Management Control

Anthony defines management control as "...the process by which managers assure that resources are obtained and used effectively and efficiently in the accomplishment of the organizations objectives." [1,p. 17]. In other words, it deals with obtaining adequate, or what may be more germane, better management. As such, it includes decision rule design, system improvement, and what Zannetos [34] calls "planning process control" (I will utilize "decision process control" for the latter to avoid semantic confusion). Decision process control is clearly a level up from operating process control.

Conventional management control systems often operate as follows. A manager is provided with certain standards or goals or quotas and periodically, performance measures are accumulated, adjusted superficially for uncontrollable variations, and compared with standard. Major unfavorable deviations result in review to determine causes and, possibly, remedial action. One problem arises as a result of the crudeness of the measurement process. Because the performance measure consists of the sum of numerous detailed measurements, substantial averaging and confounding of diverse effects takes place; determining causes retrospectively is difficult. Hence, such systems frequently are useful only in controlling extremes of management performance. A similar problem arises when organizational subunits are highly interdependent. At the gross level of measurement, separation of effect due to individual managers is also difficult. These problems suggest the desirability of more sophisticated approaches.[16]

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[16] Zannetos [34] argues this point cogently. He advocates more precise approaches to "analysis of variance and covariance."

It can be noted that in the type of "vertically integrated" management structure described here, all of the elements necessary for controlling the management process, essentially as closely as management controls the operating process, are present. To the degree that it is required (or desired) for determination of causes, variances can be analyzed at the detailed task level. For example, a major deviation in direct labor on a task can be analyzed upon the task's completion and causality apportioned among worker, supervisor, standards estimator and material supplier. For one thing, the opportunity for "squirreling" good (or more likely, fortuitous) performance to match against less favorable results would be eliminated. For another, the employment of quick and accurate feedback in control (and educational) processes has known virtues.

Decision Process Control

Stated more generally, since it is possible in these more formal systems to capture the inputs to and outputs from a manager's decisions, remedial analysis can take place at the decision process level. This potential raises some obvious questions as to desirable strategy. I know of at least one company that has built in to their on-line real-time system an "anti-meddling" logic which prevents higher level supervisors from obtaining access to their subordinates detailed data (except through the subordinate's own console).[17] Questions of interpersonal policy notwithstanding, these on-line, real-time based systems will allow "the top to control the middle just as Taylorism allowed the middle

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[17] It may be significant that the designer was a student of the late Douglas McGregor's.

to control the bottom," [20,p. 43]. It is my feeling that the presence of objective information need not preclude the use of tact in its employment.

System Evolution

A less controversial effect of the generalized systems can be found in the area of systems improvement. As a corollary to the flexible division of decision labor and the feedback of results (real or simulated), the division can change over time. What I have in mind is a role of self-improvement, or more to the point, self-automation of the man. The man can be allotted his place in the system flow chart and recourse taken to his heuristic skills when occasion arises. As he accumulates experience, his treatment of certain problems may begin to follow a pattern, a clear-cut decision "protocol" may emerge. When it does (assuming that the reward system provides him with reasonable self-interest) the decision to program the protocol for the computer can be made.[18] Given the feasibility, the automation becomes an economic question.

The presence of the man in the process is, given the current state of the art, essential. Discovery of decision rules is an inductive inferential process, based on pattern recognition, hypothesis formulation and test. The fact is that inductive inference, or even pattern recognition, is not at present very well programmed [26], and consequently is a natural area for man-machine cooperation. The automation process may be performed by someone other than the man himself. I cast the decision maker in the role of heuristic programmer mainly on the basis of my belief in the efficacy of introspection

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[18]A modeling of the decision maker of the type performed by Clarkson [5] is envisioned here.

in the protocol definition process. To the degree that this belief is well-founded, it constitutes an argument against the conventional wisdom calling for separation of the functions of system design from system operation.

The facility for system design is actually more general. When one has a system which is, in effect, a model of itself, an important class of "what would happen if?" questions deal with changes in the system procedures themselves. And avoidance of proscription of new or modified procedures may be as important as the potential of the procedures themselves. There is a related effect in the training and education of new managers. In the world I have portrayed thus far, there are valid models ranging from the most detailed to the highly aggregated version of the environment. And given the interactive mode, the neophyte can "play" with the models and gain an unparalleled understanding of both the environment and operations of the firm. The facility for gaming is totally a by-product of the operating system.

Summary of Main Effects

The primary employment of on-line, real-time systems in management control is therefore perceived to be in decision process control and improvement. The fact that these systems permit the launching of a management system with modest automatic control sophistication (i.e., with most decisions allocated to humans) while providing also for natural evolution and extension, "learning," so to speak, suggests that they will (1) be used and (2) contribute significantly to the realization of the potentials of information technology. The importance of the flexible structure may be as great in providing the means toward the end as in providing the medium for the end itself.

The system improvement role combined with the previously described man-machine coupling for operational control constitutes Simon's "...layer of nonprogrammed decision processes (carried out in a man-machine system) for monitoring the first-level processes, redesigning them, and changing parameter values." [32,p. 49].

Effects in Strategic Planning

Anthony's definition of the function is [1, p. 16]:

> Strategic planning is the process of deciding on objectives of the organization, on changes in these objectives, on the resources used to attain these objectives, and on the policies that are to govern the acquisition, use, and disposition of these resources.

That is, such decisions as new products, new plants, as well as policy formulation fall into this category. Decisions in this area are characterized by complexity and lack of structure.

Procedural Aspects

Anthony admits, Emery [10] elaborates on, and Forrester [15] argues the usefulness of models in planning. Accepting this as a point of departure, one would suppose that in problem areas in which subjective judgement plays such a key role, Licklider's [21] arguments on the importance of intertwining the human with the (computer) model are particularly applicable.

For example, some planning decisions are relatively well-structured as to procedure but heavily dependent upon subjective inputs. As a case in point, consider oil exploration or drilling decisions (or, for that matter any of several "terminal" decisions considered in the Bayesian decision theoretic

framework). The problem is not so much the complex interrelationships of the variables but the assessment of risks (subjective probabilities) and the evaluation of outcomes (subjective utility estimation). That a man-machine coupling for such decision analysis would be useful seems clear.[19]

Interaction may be even more useful the greater the complexity and the less the structure. Newell and Simon have advocated the use of heuristic programming for decisions of the type found in strategic planning, "... the way is open to deal scientifically with ill-structured problems...to make the computer coextensive with the human mind." [28, p. 9]. My point is that this is liklier to occur if the computer can be made coextensive with the human thinker during the thinking process.

Data Base Aspects

The requirement for access to global, current internal status is clearly less important for the strategic planner, whose concern is what might be beyond the corporate confines, than for the management controller, whose concern is what might be within. This might suggest no requirement for connection of the strategic planner to the corporate system described above, but several aspects argue to the contrary. First, there is a growing movement towards maintaining files on whatever data is relevant for decision making, regardless of the externality of its source.[20] Second, some internal data, if only the

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[19] Such couplings for Bayesian decision analysis have been employed and tested in Edward's "PIP" [9] and Shuford's CORTEX [31]. Both are interactive systems.

[20] See, for example, [14].

model of the firm as it exists, is undoubtedly relevant. And third, the flexibility for expansion of the data base means that *ad hoc* data can be combined with regularly available data for *ad hoc* decision making. Furthermore, the interaction and general ease of access enable a "browsing" mode of operation. That is, a planner can inquire of the status of particular variables or obtain statistical functions of the variable[21] or otherwise selectively search for and manipulate data essentially without major restrictions.

Main Effects

The value of the data base effects is obviously more speculative than the procedural aspect. The prophesied effects in the latter can be summarized as follows: to the degree that formal modeling is useful in strategic planning, interactive modeling will be more useful.

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[21]What I have in mind is interactive question answering of the type provided by the Lincoln Laboratory "Baseball" program [18].

IV. Summary and Conclusions

Some Organizational Implications

The years which have intervened since the first prophecies of Leavitt and Whisler [20] and Simon [32], have provided little basis for disagreement with their prophecies. If anything, the mechanisms for fulfillment are clearer. For example, the means for automation and the technical knowledge for accomplishing it now are available. The concomitant increase in what might be called "operational span of control" (using a somewhat discredited term to refer to the scope of activities that can be centrally controlled by one controlling entity, be it man, machine, or combination of the two) will surely cut a swath through middle management ranks. All indications point to a "rationalization" and "depersonalization" of managerial work. And the question of whether the top will tightly control the middle is one more of industrial sociological policy than technical feasibility.

The capabilities inherent in the generalized computer systems do raise some intriguing questions on one issue, this being the tendency towards "recentralization" of decisions. In the type of management systems described here, the centralized data base and decision programs certainly imply the <u>feasibility</u> of centralized decision making; but, the important points are (1) they do not <u>require</u> it and (2) they may alleviate one major reason for it. The first follows directly from the fact that the human decision-maker may be located remotely, "out in the field." The second is a more complex argument. One of the major pressures to centralize decision-making stems from locally suboptimal decisions. That is, one organizational subunit cannot

consider the status of other remote but interdependent subunits and, as a consequence, may, if allowed decision autonomy, make decisions inconsistent with overall corporate welfare. But, if the subunit can be given access to the corporate data base, then its decisions can be reconciled with full corporate status, and, in theory, be made consistent with corporate status and objectives. (This implies a problem of management control, namely: How do you reward locally altruistic but globally desirable decisions? The answer might even be that you centralize to avoid the problem.)

Decentralized decision-making of this sort might be particularly desirable in cases in which there are important, relevant, elements of data which cannot, for a variety of reasons, be captured in the central data base. Subjectivity, awkwardness of quantifiability, or sheer expense of acquisition could provide sufficient bases for absence. The clearest example of a decision maker who would require at most a central data clearing house would be the battlefield commander, whose local knowledge of situation and terrain are as vital to his decisions as the overall situation and goals. Jacob Ever [11] argues for this type of decentralized structure with shared data base for support of engineering design in a multiple division company.

It is my feeling that there will always exist situations in which some degree of local autonomy must be granted in order to allow for coping with the centrally unknown "terrain and situation." And, even in situations for which centralization is ultimately indicated, the structure provides a useful transient state in its evolution.

The Current State of the Art

At the present time, there are numerous partial implementations of these generalized systems in operation. The data base aspects of the systems has been widely exploited by airlines, railroads, and insurance companies as well as by industrial firms. Automatic control systems of modest sophistication have been installed in distribution and manufacturing systems. And time-sharing has become a fad.

A casual glance at the agenda of any computer society meeting or at the contents of professional or trade journals is sufficient to establish the exciting pace of technological development in these generalized systems. All of the major computer manufacturers offer (more-or-less) suitable hardware for these systems and some are even developing software. An assumption, based on historical patterns, is that the maturing technology and increasing demand for on-line, real-time systems will provide lower costs.

Perhaps the most exciting work in system development is still at the laboratory stage. Since time-sharing is an economic necessity for widespread experimental work in man-machine problem-solving, the facilities for coupling and evaluation of the "intertwining" are still crude. But the shape of things to come can be seen. The "OPS" group [18] at M.I.T. has developed an on-line modeling software system which should cater to the needs of the strategic planner. Several projects employing interaction for strategic planning,[22] and operational control [3] are in process as well. And as time-sharing computers for experimental work become available in universities and industry, much more work of this sort is to be predicted.

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[22] One involves constructing an interactive version of a formal strategic planning model employed by a government agency for funding and mission analysis.

All in all, the limb that Sprague climbed out on when he prophesied that "nearly all business systems will be of the on-line, real-time variety by 1970" [33,p. 3] seems shorter each passing day.

Summary

The argument has been advanced that compatible on-line real-time systems supply the key to realization of the potential so clearly foreseen in information technology. The substance of the argument has been that these systems provide simultaneously three important capabilities: a current, global data base, computational power at the moment of real-time decision, and a convenient, economically defensible interface for closely-coupled man-machine problem-solving. And, in turn, the capabilities provide important new opportunities in decision-making because they improve the quality of the data base and afford the ultimate in procedural flexibility for the decision processes. The main effects are seen in operational control and in the systems design aspects of management control, because all of the cited qualities are important in those functions. At a somewhat more speculative level, opportunities for man-machine "symbiosis" via interactive problem solving are predicted in the strategic planning function.

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